Semiannual Technical Report

A Comparative Study of Rock Stress and Property Measurement Equipment

October 25, 1971

Contract Number

H0210030

University of Idaho

Moscow, Idaho 83843

UI-BMR-2-8

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)
University of Idaho, Bureau of Mining Research, College of Mines, Moscow, Idaho, 83843

2a. REPORT SECURITY CLASSIFICATION

2b. GROUP

3. REPORT TITLE

COMPARATIVE STUDY OF ROCK STRESS AND PROPERTY MEASUREMENT EQUIPMENT

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Semiannual Technical Report, - April 2, 1971 to November 2, 1971

5. AUTHOR(S) (First name, middle initial, last name)

John R. Hoskins

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
November 2, 1971	25	75

8a. CONTRACT OR GRANT NO.
H0210030

b. PROJECT NO.
ARPA Order Number 1579, Amed. 2

c.
Program Code Number 1F10

d.

9a. ORIGINATOR'S REPORT NUMBER(S)

UI-BMR-2-8

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

Distribution of this document is unlimited

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY
Advanced Research Projects Agency, Washington, D. C.

13. ABSTRACT

This is the first Semiannual Technical Report for the reporting period from April 2, 1971 to November 2, 1971.

Data accumulation was the only activity. Analysis will follow in a later report. A brief statement of purpose and background is given and specific mention of the more accepted reports on stress and modulus gage theory, design, and very inadequate use description is presented. Brief mention is made of the questionnaire and data collection process with a listing of the number of references, questionnaires, and contacts resulting from the study to date. Little technical information is provided at this time consistent with work plans.

DD FORM 1 NOV 65 1473

Security Classification

Security Classification

KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Rock	5					
Stress, Modulus, Cost, Performance, Depth	6					
Gages, Gauges	8					
Gage, Gauges	4					
U. S. Bureau of Mines	0					
Rocha Dilatometer	0					
Glass Plug	0					
Goodman	0					
CPC	0					

Security Classification

SEMIANNUAL TECHNICAL REPORT

Date:	October 25, 1971
Our Report Number:	UI-BMR-2-8
ARPA Order Number:	1F10
Contractor:	University of Idaho, Moscow, Idaho 83843
Effective Date of Contract:	April 2, 1971
Contract Expiration Date:	April 2, 1972
Amount of Contract:	$29,697
Contract Number:	H0210030
Principal Investigator:	Dr. J. R. Hoskins
Telephone Number:	(208) 885-6376
Project Scientist or Engineer	Dr. C. J. Hall
Telephone Number:	(208) 885-6376

Sponsored by

Advanced Research Projects Agency

ARPA Order No. 1579, Amend. 2

Program Code No. 1F10

This research was supported by the Advanced Research Projects Agency of the Department of Defense and was monitored by Bureau of Mines under Contract No. H0210030

Technical Report Summary

The purpose of the study is to provide information to engineers on use, cost, time, and other factors relating to rock stress and modulus gages. This information would be oriented toward comparative selection of gages to be used in specific application.

Due to the nature of the project, only data collection through questionnaires, personal contact, and telephone is called for. No equipment purchase or intermediate conclusions have resulted.

The primary interest is directed toward collection of specific use-data on the U. S. Bureau of Mines borehole gage, CSIR "doorstopper", Griswold gage, and the Photoelastic glass plug used for in-situ rock-stress determination; and the Rocha dilatometer, Goodman jack, U. S. Bureau of Mines CPC, and the Menard pressure meter used for in-situ rock-modulus determination. Approximately 800 questionnaires have provided about 240 answers with possibly 70 meaningful sets of data. The data is continuing to come in, and follow-up on incomplete answers is required in most cases. Analysis of the data has started, but results are insufficient to provide useful information at this early date.

The only technical difficulty encountered has been the absence of the principal investigator, C. J. Hall, due to visa clearance. The project director has continued the work plan at a reduced rate pending Dr. Hall's arrival. If the absence continues much longer, it will be necessary to make other arrangements and possibly to request time extension for the project.

Table of Contents

A Comparative Study of Rock Stress and Property Measurement Equipment

Introduction

Engineering design of specific structures requires data on load, area of application of the load, material properties, and use criteria such as failure or deformation specifications. Rock mechanics or the engineering applications of rock is no exception. The major distinction is that the working structure in rock is formed by removal of material from a semi-infinite mass and the resulting skeleton is required to be self-supporting, and possibly support other structures.

Unlike fabricated or constructed structures, the design load is unknown since the semi-infinite mass of rock causes the load through some combination of geologic and gravitational conditions. The resulting effect is an unknown load in an unknown direction applied over a questionable area. To further complicate the problem, most critical conditions relate to stress concentrations due to the opening formed in the rock. The concentrations are a function of geometry and rock properties. The geometry may or may not be well defined because fracture or time-dependent effects may make the visual and effective opening shape quite different. The properties are also poorly defined because of mass effects that exhibit hetrogeneity and anisotropy dependent on volume. Controlled laboratory test data on finite samples and field data on a more massive scale often may not

coincide. Due to many factors, realistic measurement of in-situ stress and modulus would appear most needed.

Some development had to be made to provide these data, if a change from artisanship to engineering was to be expected. These were attempted and gradually techniques were developed by many investigators over the past 25 years with increasing frequency and with varying success. Many reports of the theoretical principles, gage design, laboratory application and testing have been written which are listed in the attached references. However, reports of application of these gages in field conditions to get meaningful results are few.

The Purpose of Study

The objectives of the present study are to collect data on field tests in which stress and modulus gages have been used. The gages for measuring stress that are of particular interest are: U. S. Bureau of Mines borehole gage, CSIR "doorstopper", Griswold gage, and Photoelastic glass plug; and the gages for measuring modulus that are of particular interest are: Rocha dilatometer, Goodman jack, U. S. Bureau of Mines CPC, and Menard pressure meter. Other gages were considered whenever possible, and when specifically reported in the questionnaire.

There would appear to be no valid reason for repeating previously chronicled data on theory or design of any gage, but a compendium of use

data such as best application, cost, depth, difficulty, reliability, etc., could be of considerable value to a prospective user. This, then, is the primary reason for the study--to provide information to engineers who are faced with the selection of the most appropriate equipment for a given situation in which the stress and rock modulus must be determined.

Background

During several years work in rock mechanics in which it was frequently necessary to recommend the best way of determining in-situ stress or modulus, the investigators were never able to ascertain adequate information about gage use for comparative decisions. Choice was too often confined to personal opinion or proprietary enthusiasm. This seemed to be a common problem for most potential gage users. The present literature search shows little improvement although some of the individual papers are quite helpful for specific gages.

Leeman [1/] described a number of gages with details of design, but did not give adequate information for selecting one gage in preference to another. Obert and Duvall [2/] also presented information on theory and design of some gages, but again with limited use data. Woodruff [3/] presented some application data as well as theory and design of some gages. Information on individual gages was presented in more detail in separate papers at an early symposium edited by Spokes [4/]. Some of the papers were more specific on the problems and costs so that selection could be made more intelli-

gently. It was an improvement over the previous symposium discussion at McGill in 1962 by Panek [5/]. An attempt was made by Fairhust [6/] to compile several of these reports in one to provide a ready source of information on the subject. It still did not give adequate data for use selection. Possibly a better presentation for the purpose is the work by Abel[7/] in which most of the same gages were examined, but with a different intent. His purpose was to evaluate the gages and instruments for use on the Project Payette. His report chronicled information for one specific application which this investigation is to do for more general use.

Other data accumulated, and in process of accumulation, almost exclusively pertains to individual gages. These are to be compiled and analyzed during the next phase of this project.

Theory

Although the purpose of this study is to explore stress and modulus gage use, it is appropriate to provide information on the theory behind the gages for anyone wishing to compare their use and applicability in more detail.

Reddy's [8/] two-dimensional photoelastic investigation of stresses surrounding the pilot hole region during overcoring shows high stress concentration in the potential overcore and an explanation for discing of cores which is a frequent problem in high stress areas. It can be seen that gage positioning and interpretation of deformation becomes important in the complex stress field that results from the process. Mahtab and Goodman [9/] have used finite element analysis to investigate nonlinear stress-strain laws at the bottom of well bores at 6000-foot depth. Problems of nonlinearity although effective over only one-quarter hole radius, nevertheless would appear to effect gages dependent on surface measurements at well bottom. Van Heerden[10/] shows that fracture around the borehole end can be expected but does not interfere with the doorstopper gage use. After considering both flat and spherical hole bottom configuration, he determined the flat hole bottom [11/] was satisfactory for his purposes.

Several authors mentioned previously (1, 2, 3, 4, 5, 6, 7) have investigated two or more gages for comparative purposes. These reports vary from the theoretical to state-of-the-art information with the most complete treatment being given by Fairhurst [6/], Leeman [1/], and Obert[2/]. Leeman's treatment while not complete offers the reader the mathematical, description of instru-

ments, and information about the use of several of the devices. His classification of: 1) borehole deformation strain cells, 2) borehole inclusion stressmeters, and 3) borehole strain gage devices are a convenient method of distinguishing between groups of borehole measuring devices to determine stress. No such reports or classification has been found for modulus determinations. It must also be remembered that these instruments have been designed on elastic principles. While many applications are of elastic conditions in which even fractured ground give acceptable elastic response, long term tests on some rock material result in time-dependent-relationships. Some rock exhibits these time-dependent properties under short-period tests. When encountered, devices incorporating rheological principles should be used on rocks of this type.

These theoretical presentations, when appropriate, will be included in the final report for completeness, or will be referred to for easy access. The engineer must be aware of limitations of theory as well as of gage use. For example, several of the gages are designed to determine principle stresses only if the borehole is parallel to the third principle stress. If this cannot be determined for certain in the field, another method of investigation becomes necessary. Other limitations of theory exist and will be presented in the final report.

Investigative Procedure

Initial review of reports on gage use corroborated the author's belief of a tendency toward positive reporting with only a minimum and usually a complete absence of adverse information being included. As negative as well as positive information was part of the purpose of this investigation, it was necessary to collect first-hand comments from users to get a more accurate assessment of operator difficulty, costs, time, and weaknesses. Only with these data and comments would a prospective user be able to make a meaningful selection between gages for his particular condition.

The first step in any investigation is the collection of published information, but in this study authors' addresses were also needed. This resulted in severe complications because a surprising number of professionals have a high rate of migration in a period of five years.

A questionnaire was devised (see Appendix) to get as detailed data as possible from each user. One questionnaire was sent to each operator or anyone believed to have been an operator of any rock-type gage. Duplicate questionnaires were sent to those indicating use of more than one gage. Follow-up after no return of an inquiry is by letter or telephone. If returned unopened, additional effort is made to establish a correct address.

Personal contact was made with individuals separately or during professional meetings to establish additional information, clarify details, or get names of other investigators. In all, approximately 800 questionnaires were sent, both domestic and foreign, with about 240 replies being received.

Most foreign replies have not had an opportunity to arrive yet. Of the 240 replies, only 70 have been informative to any degree, and less than 50 have detailed use data that is of value. Direct contact has netted approximately an equal amount of data, some of it overlapping.

The most difficult part of both written and verbal contact was to arrive at common denominators of cost, ease or difficulty of operation, set-up time, reliability, and problems encountered. Efforts are still being tried to make these more fruitful, as well as continue to gather additional information.

Data Collected

The objective of the study is to get working data on the following gages:

Stress Gage

1. U. S. Bureau of Mines borehole gage
2. CSIR "doorstopper"
3. Photoelastic glass plug
4. Griswold gage

Modulus Gage

1. Menard pressure meter
2. Rocha dilatometer
3. U. S. Bureau of Mines CPC
4. Goodman jack

If information on other gages becomes available, and is appropriate, it will be included also. Since most gages have been described in detail, and their theoretical concepts have been well chronicled, no attempt will be made to repeat this information here. For completeness, it will be included in the appendix of the final report.

Questionnaires received at the time of this report have generally been inadequate in their answers to questions on costs and specific difficulties encountered. The two main reasons for the lack of data are: incomplete

response, which is being given individual follow-up during the next half; and inadequate records of this information by the user. For example, the U. S. Bureau of Mines prime objective is experimental information on feasibility with cost being of secondary importance. Often the user had only limited experience with the gage. In addition to being an unfair reflection on the gage, except possibly the training needed to use it, these data do not establish the critical information sought for comparative purposes. It is expected that continued investigation will amplify these data, mainly through direct telephone or personal contact.

No conclusions will be presented in this interim report nor will it be appropriate to present use charts, recommendations, or selection guides due to the small quantity of information available. These will be left for the final report at the end of the second six-month period.

Information received for the specific gages was:

Stress Gages	Publications	Questionnaires	Personal Discussion
USBM Borehole	23	16	10
CSIR Doorstopper	9	9	2
Photoelastic Plug	8	9	8
Griswold	4	1	2
Modulus Gages			
Menard Pressuremeter	5	1	0
Rocha Dilatometer	2	1	3
USBM CPC	1	6	2
Goodman Jack	11	7	5
Other Gages			
Hast	2	1	0
White Pine Solid Inclusion	3	3	2
CSIR 3-D Cell	17	0	2
Soil Stress Cell	2	0	0
Deformation Gage	2	1	0
Flatjack	4	1	2
Hydraulic Cell	2	2	2
Hydrofract	0	2	4
Photoelastic Coating	0	1	6
SR-4 Strain Gages	2	2	5
Soiltest Unit	1	3	0
Seismic	1	1	5
Sweeny Tescon	1	1	0
Talobre	1	1	0
Terrametrics	1	0	1
TiWag Radial Jack	5	0	0
Extensometers	0	2	4
Potts Stressmeter	5	1	1

Attempts to analyze and chronicle these data are starting according to program plans, but are of insufficient value to be presented here. These will be left for the final report.

Conclusions

At this point, the only conclusions that can be made are:

1. It is almost impossible to get specific data on costs and difficulties from operators.
2. Problems of a specific nature such as design errors, malfunctions of gages and performance difficulties are not chronicled by the designer and frequently when reported by the user are omitted from final reports on a project.

References Cited

1/ Leeman, E. R. The Measurement of Stress in Rock. Journal of the South African Institute of Mining & Metallurgy, Vol. 65, No. 2, Sept. 1964, pp. 48-114; No. 4, Nov. 1964, pp. 254-284.

2/ Obert, Leonard, and W. I. Duvall. Rock Mechanics and the Design of Structures in Rock. Wiley, New York, 1967, pp. 236-374, 409-458.

3/ Woodruff, Seth D. Methods of Working Coal and Metal Mines. Vol. 1, Pergamon, New York, 1966, pp. 95-116, 381-425, 449-461.

4/ Spokes, E. M. and C. R. Christiansen. Procedures of the Sixth Symposium on Rock Mechanics. University of Missouri at Rolla, Oct. 1964, pp. 427-449, 498-500, 617-648, 721-768.

5/ Panek, Louis A. Measurement of Rock Stress. Procedures of the Rock Mechanics Symposium, Dept. of Mines and Technical Survey, Ottawa, McGill University, Montreal, Sept. 1962, pp. 53-68.

6/ Fairhurst, Charles. Methods of Determining In-Situ Rock Stresses at Great Depth, Technical Report No. 1-68, Missouri River Division, Corps of Engineers, Omaha, Nebraska, 1968.

7/ Abel, John F. Evaluation of Stress Instrumentation for Project Payette. U. S. Department of Interior, Geological Survey, Special Projects 22, Technical Letter, June 1968.

8/ Reddy, V. S. A Study of Stress Distribution and Measurement of Axial Strain Around a Pilot Hole During Overcoring. M. S. Thesis, University of Missouri at Rolla, 1966.

9/ Mahtab, M. A. and R. E. Goodman. Stresses Around Wellbores in Nonlinear Rock, SPE Journal, Sept. 1968, pp. 304-312.

10/ Van Heerden, W. L. Potential Fracture Zones Around Boreholes With Flat and Spherical Ends. International Journal of Rock Mechanics and Mining Sciences, Vol. 6, No. 5, pp. 453-463, 1969.

11/ Van Heerden, W. L. Stress Concentration Factors for the Flat Borehole Encl. for Use in Rock Stress Measurements. Engineering Geology, Vol. 3, pp. 307-323.

GENERAL REFERENCES

1. Austin, W. G. Field and Laboratory Tests for "Safety of Dams" Investigation at Salt River Project, Arizona. Division of Research, Office of Chief Engineer, Bureau of Reclamation, Feb. 1970.
2. Austin, W. G. Development of a Stress Relief Method with a Three-directional Borehole Deformation Gage. Division of Research, Office of Chief Engineer, Bureau of Reclamation, March 1970.
3. Coates, D. F. and F. Grant. Stress Measurements at Elliot Lake. The Canadian Mining and Metallurgical Bulletin, May 1966, Montreal, Vol. 69, No. 649, pp. 182-192.
4. Conway, John P. Progress Report on Crescent Mine Overcoring Studies, Support Load Prediction Project. January 10, 1968 through April 15, 1968.
5. Conway, John P. Suggestions for Improvement of the Overcore Method. Nov. 4, 1968. (rough draft)
6. Conway, John P. Goodman Jacking Tests. May 2, 1969. In-House Report SMRC
7. Crouch, S. L. and C. Fairhurst. A Four-component Borehole Deformation Gage for the Determination of In-situ Stresses in Rock Masses. International Journal of Rock Mech. and Mining Sciences, Vol. 4, 1967, pp. 196-209.
8. Dodd, Jerry S. A Technical Presentation of Morrow Point Underground Powerplant Rock Mechanics Investigations. U.S. Dept. of Interior, Bureau of Reclamation, Denver, Colorado, March 1967.
9. Fisher, Hugo. Static Stress Determinations at Oroville Underground Powerhouse. State Water Facilities, Oroville Division, State of Calif. The Resources Agency Dept. of Water Resources, Rock Mechanics Report No. RM-4 Dec. 1963

10. Fitzpatrick, J. Biaxial Device for Determining the Modulus of Elasticity of Stress Relief Corps. USBM No. RI 6128, April 1962.

11. Gates, Richard H. Project Gondola. March 1967. Corp. of Engrs. Livermore, Calif. undated.

12. Francq, J. Report of Pressure Meter Investigation, PreGondola - 1. U.S. Army Corps of Engineers, Nuclear Cratering Group. Livermore, Calif.

13. Gates, Richard H. Pressuremetric Investigation after Blasting Part 2, Pre-Gondola I Project - Fort Peck Montana for Nuclear Cratering Group. U.S. Army Corps of Engineers. Livermore, Calif. undated.

14. Geocel, Inc., Golden, Colorado. Schematic Drawing Illustrating Components of Menard Pressure Meter and its Principle of Operation. undated.

15. Geocel, Inc., Golden Colorado. The Geocel Pressuremeter - Interpretation of a Pressuremeter Test. undated.

16. Goodman, Richard E., Tran K. Van and Francois E. Heuze. The Measurement of Rock Deformability in Bore Holes on Earth - Adaptability to a Lunar Exploration Program. NASA Contractor Report, NASA CR-61202, Feb. 1968.

17. Goodman, R. E., Tran K. Van and F. E. Heuze. The Measurement of Rock Deformability in Boreholes. Proc. 10th Symp. Rock Mech. Univ. Texas, 1968.

18. Griswold, G. B. How to Measure Rock Pressures. New Tools and Proved Techniques Aid Mine Design. Engineering and Mining Journal, Vol. 164, No. 10, 1963, pp. 90-95.

19. Gupta, K. P. How to Measure Rock Pressures. Engineering and Mining Journal, Oct. 1958, pp. 95-100.

20. Hartman, Burt E. Rock Mechanics Instrumentation for Tunnel Construction. Terrametrics, Inc., Golden, Colorado. 1967.

21. Hawkes, I. Theory of Photoelastic Biaxial Strain Gage. International Journal of Rock Mech. and Mining Sciences, Vol. 5, No. 1, Jan. 1968, pp. 57-63.

22. Hawkes, I. and S. Moxon. The Measurements of In-situ Rock Stress Using the Photoelastic Biaxial Gage with the Core Relief Technique. International Journal of Rock Mech. and Mining Sciences, Vol. 2, No. 4, 1965, pp. 405-419.

23. Heuze, F. E. and R. E. Goodman. Techniques for Measuring Stresses in Rock on the Earth - Adaptability to a Lunar Exploration Program. NASA Contractor Report. NASA CR-61203, Feb. 1968, pp. 2-44.

24. Heuze, F. E. Sources of Errors in Rock Mechanics Field Measurements, and Related Solutions. Int. Journal of Rock Mechanics Science. Pergamon Press. 1970, pp. 1-14.

25. Heuze, Francois E., Richard E. Goodman and Ann Bornstein. Numerical Analyses of Deformability Tests in Jointed Rock - "Joint Perturbation" and "No Tension" Finite Element Solutions. Rock Mechanics - Felsmechanik, Vol. 3, No. 1, 1971.

26. Hiltscher, R. Measurement of the Modulus of Deformation of a Rock in the Direction of a Borehole. Engineering Geology Vol. 2, No. 1, 1967, pp. 19-26. (In German)

27. Hooker, Verne E., Harry R. Nicholls and Wilbur I. Duvall. In-situ Stress Determinations in a Lithonia Gneiss Out Crop. Oral presentation at annual meeting of Eastern Section of Seismological Society of America, Ann Arbor, Michigan, Oct. 10, 1964. Earthquake Notes, Sept-Dec., 1964, Vol. 35, No. 3-4, p. 46.

28. Hooker, Verne E. and Wilbur I. Duvall. Stresses in Rock Outcrops near Atlanta, Georgia. U.S. Dept. of Interior, Bureau of Mines, RI 6860, 1966.

29. Hooker, Verne E. and Charles F. Johnson. Near-Surface Horizontal Stresses Including the Effects of Rock Anisotropy. U.S. Dept. of Interior, Bureau of Mines, RI 7224, Feb. 1969.

30. Judd, W. R. Rock Stress, Rock Mechanics and Research, Conference - State of Stress in the Earth's Crust, Santa Monica, June 1963. Elsevier, New York, 1964, pp. 5-54.

31. Kent, Ray Clark. A Strain Gage for Use in Drill Holes. M.S. Thesis, Univ. Utah, 1961.

32. Kruse, George H. Powerplant Chamber Under Oroville Dam. Presented at the ASCE. National Water Resources Engineering Meeting, Underground Chambers, Phoenix, Arizona, Jan. 11-15, 1971.

33. Labasse, Henri. Ground Stress in Longwall and Room-and-Pillar Mining. Proceedings of the Rock Mechanics Symposium held at Univ. of Toronto, January 15-16, 1965. Mines Branch Dept. of Mines and Technical Surveys, Ottawa, 1965, pp. 47-64.

34. Leeman, E. R. Experience Throughout the World with the CSIR Doorstopper Rock Stress Measuring Equipment. CSIR, R MEG 310, undated.

35. Leeman, E. R. The Determination of the Complete State of Stress in Rock in a Single Borehole. Laboratory and Underground Measurements. International Journal of Rock Mech. and Mining Sciences, Vol. 5, No. 1, Feb. 1967, pp. 31-56.

36. Leeman, E. R. The "Doorstopper" and Triaxial Rock Stress Measuring Instruments Developed by the CSIR. Journal of the S. African Institute of Mining and Metallurgy, Vol. 69, No. 7, Feb. 1969, pp. 305-339.

37. Li, Bjorn. Natural Stress-Values Obtained in Different Parts of the Fennoscanidan Rock Masses. 27 Proceedings 2nd Congress. Laboratorieingenior, Institutt for Gruvedrift, NTH, Trodheim, Norway. pp. 1-28, undated.

38. Menard, Louis. Rules for the Calculation and Design of Foundation Elements on the basis of Pressuremeter Investigations of the Ground, undated.

39. Merrill, Robert H. and Jon R. Peterson. Deformation of a Borehole in Rock. U.S. Dept. of the Interior, Bureau of Mines, RI 5881, 1961.

40. Merrill, Robert H., James V. Williamson, David M. Ropchan and George H. Kruse. Stress Determinations by Flatjack and Borehole Deformation Methods. U.S. Dept. of Interior, Bureau of Mines, RI 6400, 1964.

41. Merrill, R. H. Three-component Borehole Deformation Gage for Determining the Stress in Rock. U.S. Bureau of Mines, No. RI 7015, Aug. 1967, 38 pp.

42. Nair, O. B. and J. E. Udd. Stresses Around Openings in a Plate Due to Biaxial Loads Through a Superpositioning Technique. Proceedings of the Rock Mechanics Symposium held at Univ. of Toronto, January 15-16, 1965. Mines

Branch Dept. of Mines and Technical Surveys, Ottawa, 1965.

43. Obert, L., Robert H. Merrill and Thomas A. Morgan. Borehole Deformation Gage for Determining the Stress in Mine Rock. USBM RI 5978, 1962.

44. Roberts, A., I. Hawkes, F. T. Williams and R. K. Dhir. A Laboratory Study of the Photoelastic Stressmeter. Int. Journal of Rock Mech. and Mining Sciences, Vol. 1, No. 3, May 1964, pp. 441-458.

45. Roberts, A. Photoelastic Glass Insertion Stressmeter. Relation to Friction on the Layer, Direction of Extraction and Progress of Working. Engineer, London, Vol. 220, July 30, 1965, pp. 165-171.

46. Rose, H. and A. Roberts. The Measurement of In-situ Stress Strain and Load by Optical Techniques. Unclassified Microfilm AD 474 206, Sept. 65.

47. Stowe, Richard L., U.S. Army Corps of Engineers. Comparison of In-situ and Laboratory Test Results on Granite. Society of Petroleum Engineers of AIME, Paper No. SPE 3217, Reprint, Undated.

48. Royea, M. J. and K. G. Davies. Rock Mechanics Applied to Extraction of Pillars at Sullivan Mine. Stress Deformation. Canadian Mining and Metallurgical Bulletin, Vol. 61, No. 678, Oct. 1968, pp. 1185-1194.

49. Royea, M. J. Rock Stress Measurement at the Sullivan Mine. Fifth Canadian Symp. on Rock Mech., Univ. of Toronto, Dec. 1968.

50. Sellers, J. B., G. R. Haworth and P. G. Zambas. Rock Mechanics Research on Oil Shale Mining. Colorado School of Mines Research Foundation, Undated.

51. Singh, Madan M. and Jan M. Mutmansky. Photoelastic Devices for Mining. Engineering and Mining Journal, Dec. 1965.

52. Slope Indicator Company. Goodman Jack Borehole Testing Device for In-situ Rock Properties. 1105 N. 38 Street, Seattle, WA 98103 undated.

53. Slope Indicator Company. Goodman Jack; NX - Plate Bearing Test. See above.

54. Slope Indicator Company. Instructions Goodman Jack Model 52101 and 52102. 3668 Albion Place N., Seattle, Wash. 98103 undated

55. Suzuki, K. Fundamental Study on the Rock Stress Measurement by Borehole Deformation Method. 1st Congr. Int. Soc. Rock Mech., Lisbon, 1966.

56. U.S. Dept. of Interior, Bureau of Mines. International Symposium on Mining Research, Univ. of Missouri, School of Mines and Metallurgy, Rolla, Missouri. Feb. 22-25, 1961.

57. U.S. Army Engineer Waterways Experiment Station, Vicksburg, Missippi. Results of In-situ Modulus of Deformation Test, Cannelton Lock and Dam. Miscellaneous Paper C-71-4, May 1971.

58. Van Heerden, W. L. Stress Concentration Factors for the Flat Borehole End for Use in Rock Stress Measurements. CSIR, R MEG 281. June, 1969

59. Van Heerden, W. L. Potential Fracture Zones Around Boreholes with Flat and Spherical Ends. CSIR, R MEG 285. 1969.

60. Van Heerden, W. L. and F. Grant. A Comparison of Two Methods for Measuring Rock Stress in Rock. CSIR, R MEG 233, 1967.

61. Waddell, Galen G. and Eugene H. Skinner. Progress Report Summary - Crescent Mine. June 1, 1968 to June 30, 1969.

62. Wallace, George B., Edward J. Slebir and Fred A. Anderson, U.S. Dept. of the Interior, Bureau of Reclamation, Denver. Foundation Testing for

Auburn Dam. 11th Symp. on Rock Mech., Univ. of Calif., Berkeley, Calif., June 16-19, 1969.

63. Wilson, A. H. A Laboratory Investigation of a High Modulus Borehole Plug Gage for the Measurement of Rock Stress. 4th Symp. Rock Mech., Penn. State Univ., Apr. 1961. Bulletin of the Mineral Industries Experimental Station, Penn. State Univ, pp.185-195.

64. Wright, F. H. In-situ Stress in Granite, Project Shoal. Lucius Pitkin, Inc., AEC Report VUF-2600, May 1964, 76 pp.

Appendix

Questionnaire

Sent to all gage users.

Return to: University of Idaho
Bureau of Mining Research
J. R. Hoskins
Moscow, Idaho 83843

Telephone: 208-885-6376

Name:______________________________

Company or
Affiliation:__________________________

Address:_____________________________

Telephone:___________________________
(Please correct the above)

QUESTIONNAIRE

Dear Sir:

I am collecting operational data on rock stress and modulus gages. My principal objective is to learn what gages have been used in in-situ rock or in underground installations for determining stress and modulus and what results have been obtained from these gages. Information concerning the borehole deformation gage, doorstopper, Griswold gage, photoelastic glass plug, Goodman jack, USBM cylindrical pressure cell, and Rocha dilatometer will be especially useful.

Your help in filling out the following questionnaire will be appreciated. It is hoped that the results will provide a ready source of information on gage selection, use, cost, and operational characteristics. If you do not have complete information, please estimate and so indicate and fill out all data wherever possible. Would you please send copies of any articles or papers which you have written on modulus or stress gages?

MODULUS GAGES, STRESS GAGES (PLEASE CROSS OUT ONE)

Have you or any member of your group used the gages?__________Name of the gage.____________________How many times have you used the gage?____________The number of people required to use it.________

What crew size do you recommend?_______Did you get the data desired?________

How long did it take to get this data?____________________________

Did you have difficulty?_______What were these difficulties?____________

____

Is any type of rock (i.e., granite, quartzite) more difficult than another?______

What kind?_______________Why?____________________________

____

What kind of training was required in order to get satisfactory data?____________

____

How long does this training take?____________Are there special techniques

needed?____

____

Are there difficulties in getting data at depth?______________________________

What are these?____

Are there difficulties due to rock conditions? (i.e., moderately fractured rock)

____

What are these?____

____

What is the maximum depth at which you have gotten information?_______________

What is the limiting depth for this method?____________________________________

How much does it cost to get information at 5-foot intervals?________________

Does it cost more with depth?____

How much per 5-foot intervals to 20 feet?____________to 50 feet?____________

to 100 feet?____________to 200 feet?____________

How accurate are your results?____

Have you checked your data by other methods?_______________________________

Do you use other intervals and hole depths?____________What are these?_________

Is there an optimum depth of hole to get reliable data?______________________

Is there an optimum hole depth for practical use of the instrument?___________

Where can the instrument be purchased?______________________________________

____

Cost of the instrument $________Cost of calibration of the instrument?_________

Cost of preparing for a test at the site $____________________________________

Material and labor costs for conducting the test $_____________________________

Please describe the field procedure used.____________________________

____

____

____

Please describe the limitations of the instrument.____________________

____

____

____

____

What do you consider to be the instrument's best points and best application?

____

____

What do you consider to be the instrument's weak points?______________

____

____

What are the recommendations for improvement of the gage?_____________

____

____

Do you have information on other gages of the rock stress or modulus type?________

May I send you another questionnaire?__________How many________________

Can you give the name and address of one or more investigators who have used these or other gages in underground investigations?

Name:______________________ Name:______________________

Address:___________________ Address:___________________

Telephone:_________________ Telephone:_________________

Name:______________________ Name:______________________

Address:___________________ Address:___________________

Telephone:_________________ Telephone:_________________